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RESEARCH MEMORANDUM

EFFECT OF CAMBER ON THE DRAG OF A BODY OF REVOLUTION

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RESEARCH MEMORANDUM

EFFECT OF CAMBER ON THE DRAG OF A BODY OF REVOLUTION

By Robert R. Dickey

SUMMARY

An investigation was conducted to determine the effect of camber on the drag of a body of revolution. The drag of a straight body of revolution was measured and compared with that of a body that differed only in that its center line was cambered in the form of a parabola.

The minimum drags of both bodies were measured at Mach numbers from 0.6 to 1.4 at a constant Reynolds number of 8.75 million based on body length. Boundary-layer trips were applied to the nose of both models in order to fix the transition point and eliminate skin-friction drag as a variable.

The addition of a small amount of camber was found to cause very little increase in the minimum foredrag of the model tested. This result is in agreement with theory.

INTRODUCTION

Many of today's high-speed airplanes have fuselages that are cambered. This camber is usually the result of practical considerations connected with the problems associated with the extreme nose-high landing attitude required of these airplanes. Thus, the rear of the fuselage may be swept upward to provide increased ground clearance for the fuselage and to avoid undue length and weight of the landing gear. On other airplanes, the forward part of the fuselage may be drooped or curved downward in order to provide the pilot with improved visibility and also to avoid an excessively long nose-wheel landing gear.

There is little experimental information available concerning the effect of body camber on the drag of body or body-wing combinations at sonic and supersonic speeds. Reference 1 presents results for two wing-body-vertical-tail configurations differing only in the amount of body camber. One configuration had a straight uncambered fuselage while the

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other had a fuselage that was swept upward at the rear. The maximum amount of camber of the upswept fuselage was approximately 1.8 percent of the body length. The results presented in reference 1 indicate that the addition of body camber to such a configuration would result in pronounced trim drag increases at sonic and supersonic speeds (48-percent increase in C_D at $M = 1.0$ and 6-percent increase at $M = 1.4$).

The purpose of the investigation reported herein was to determine the effect of camber on the drag of a body alone. Two bodies, one uncambered and the other with a parabolic center line, were tested through a Mach number range of 0.6 to 1.4 at a Reynolds number of approximately 8.75 million based on body length. The angle of attack was varied sufficiently to define minimum drag at each Mach number. The resulting experimental effect of camber is compared herein with the theoretical effect indicated by some unpublished work of R. T. Jones.

NOTATION

C_D	foredrag coefficient, $\dfrac{\text{foredrag}}{q\pi {d_o}^2/4}$
ΔC_{D_W}	incremental wave-drag coefficient, $\dfrac{\text{wave drag due to camber}}{q\pi {d_o}^2/4}$
d_o	maximum body diameter
h	maximum camber of body center line
l	body length
r	body radius
M	free-stream Mach number
q	free-stream dynamic pressure
x,y	Cartesian coordinates with origin at a point corresponding to the nose of the straight body (see fig. 1)

MODELS

Drawings of the models tested are shown in figure 1. The basic model was a straight body of revolution with a fineness ratio of 10 and was formed by superimposing the area distribution of a Sears-Haack body onto that of a Kármán ogive. The equation of the body and a tabulation of the body radii are given in table I. The cambered body had the same radius for a given x station as the basic model. The radii of the cambered body were measured from a parabolic center line normal to a horizontal reference line (see fig. 1). The maximum displacement of the nose of the cambered body model when measured from a horizontal reference line through the center of the base was arbitrarily chosen to be 4/3 of the radius of the body at its midlength station. This corresponds to a maximum camber of 1.7 percent of the body length. The coordinates of the parabolic center line are given in table II.

APPARATUS AND TESTS

The tests were conducted in the Ames 2- by 2-foot transonic wind tunnel. This wind tunnel has a ventilated test section that permits continuous choke-free operation through the transonic speed range. A complete description of the wind tunnel may be found in reference 2. The models were supported in the tunnel by means of a 1-inch-diameter, sting-type support. Values of drag were measured by means of an internal strain-gage balance.

The models were tested through a Mach number range of 0.6 to 1.4 at a constant Reynolds number of 8.75 million based on body length. The uncambered body was tested only at zero angle of attack. The cambered body, however, was tested through a small angle-of-attack range of approximately $\pm 2.5^{\circ}$ in order to make certain the minimum drag of the model was obtained. The 0° reference line from which the angle of attack of the cambered body was measured was assumed to be a straight line extending through the nose and center of the base of the model.

Roughness in the form of carborundum grit was applied to the nose of both models in order to fix the transition point and eliminate skin-friction drag as a variable. A turbulent boundary layer was obtained by selecting the grain size and location of the carborundum in accordance with information given in reference 3.

The drag data have been adjusted for the difference between the free-stream pressure and the pressure acting on the base of the model so that all drag data presented are actually foredrag. The effect of support interference on the foredrag of the models is believed to be small for the size of the support used during these tests. Since the sting interference effect would be the same for both models, no correction for this effect has been applied to the data.

The accuracy of the foredrag coefficients is believed to be ± 0.002.

RESULTS AND DISCUSSION

The minimum drag coefficients for both the cambered and basic bodies are shown in figure 2 as a function of Mach number. The minimum drag of the cambered body occurred at small negative angles of attack (approximately -1°). The drag coefficients of the cambered body at zero angle of attack are also shown in figure 2. It is apparent that the difference in drag between the two bodies is very small, approximately the same order of magnitude as the accuracy of the drag measurements (±2 percent).

R. T. Jones, in some unpublished work, has expressed the additional wave drag due to camber of a closed Sears-Haack body with a parabolic center line as follows:

$$\Delta C_{D_W} = 6\pi^2(M^2 - 1)\left(\frac{d_o}{l}\right)^2\left(\frac{h}{l}\right)^2$$

Thus it may be seen that the drag due to camber is inversely proportional to the square of the fineness ratio and directly proportional to the square of the camber-to-length ratio; therefore, the greatest drag penalties would occur at high Mach numbers for bodies of low fineness ratio and large amounts of camber.

If the cambered body which was used in this investigation is approximated by a closed Sears-Haack body having the same length, maximum diameter, and maximum amount of camber, it may be shown by Jones' equation that the additional wave drag is negligibly small (0.3 percent of the straight body at $M = 1.4$). This result is in agreement with the experimental results of this investigation.

It is of interest to note that the application of Jones' equation to a closed Sears-Haack body that approximates the cambered fuselage of reference 1 again gives a negligibly small drag increase (0 percent at $M = 1.0$ and 0.1 percent at $M = 1.4$). Thus, the large increases in drag shown in reference 1 for the complete body-wing-tail configuration must be attributed to an effect other than that due directly to the body camber.

CONCLUDING REMARKS

From the results of this investigation, it is concluded that the minimum foredrag of a body of revolution, having a fineness ratio of approximately 10, is increased very little in the transonic speed range by the addition of a moderate amount of camber to the body. This conclusion is in agreement with theory.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., May 23, 1956

REFERENCES

1. Parks, James H.: Transonic Longitudinal Aerodynamic Effects of Sweeping Up the Rear of the Fuselage of a Rocket-Propelled Airplane Model Having No Horizontal Tail. NACA RM L54K12, 1955.

2. Spiegel, Joseph M., and Lawrence, Leslie F.: A Description of the Ames 2- by 2-Foot Transonic Wind Tunnel and Preliminary Evaluation of Wall Interference. NACA RM A55I21, 1956.

3. Luther, Marvin: Fixing Boundary-Layer Transition on Supersonic-Wind-Tunnel Models. CIT Jet Propulsion Lab., PR No. 20-256, Aug. 12, 1955.

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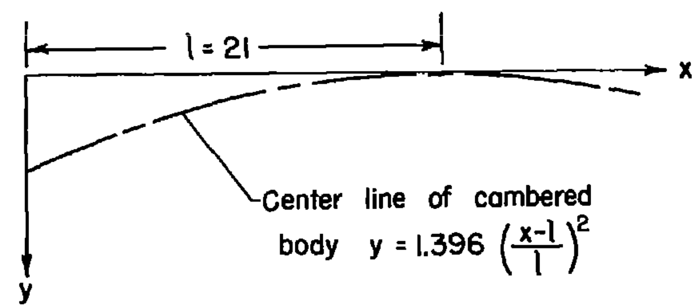
TABLE I.- BODY ORDINATES

$$r^2 = \frac{0.003545}{\pi}\left\{\left(x - \frac{l}{2}\right)\sqrt{lx - x^2} + \left(\frac{l}{2}\right)^2\left[\frac{\pi}{2} + \sin^{-1}\left(\frac{2x}{l} - 1\right)\right]\right\} + \frac{0.0255}{\pi}\left(\frac{2}{l}\right)\left(lx - x^2\right)^{3/2}$$

Body station, x, in.	Body radius, r, in.	Body station, x, in.	Body radius, r, in.
0	0	10.000	1.037
.250	.100	10.500	1.047
.500	.167	11.000	1.048
.750	.224	11.473	1.050
1.000	.276	12.000	1.048
1.500	.367	12.500	1.044
2.000	.447	13.000	1.036
3.000	.584	13.500	1.027
4.000	.697	14.000	1.013
5.000	.790	14.500	.998
6.000	.867	15.000	.979
6.500	.900	15.500	.958
7.000	.930	16.000	.934
7.500	.955	17.000	.879
8.000	.978	18.000	.814
8.500	.997	19.000	.744
9.000	1.014	20.000	.673
9.500	1.027	21.000	.625

TABLE II.- CURVATURE OF CAMBERED BODY CENTER LINE



Body station, x, in.	y, in.	Body station, x, in.	y, in.
0	1.396	11.000	0.317
1.000	1.266	12.000	.256
2.000	1.143	13.000	.203
3.000	1.026	14.000	.155
4.000	.915	15.000	.114
5.000	.810	16.000	.079
6.000	.712	17.000	.051
7.000	.620	18.000	.029
8.000	.535	19.000	.013
9.000	.456	20.000	.003
10.000	.383	21.000	.000

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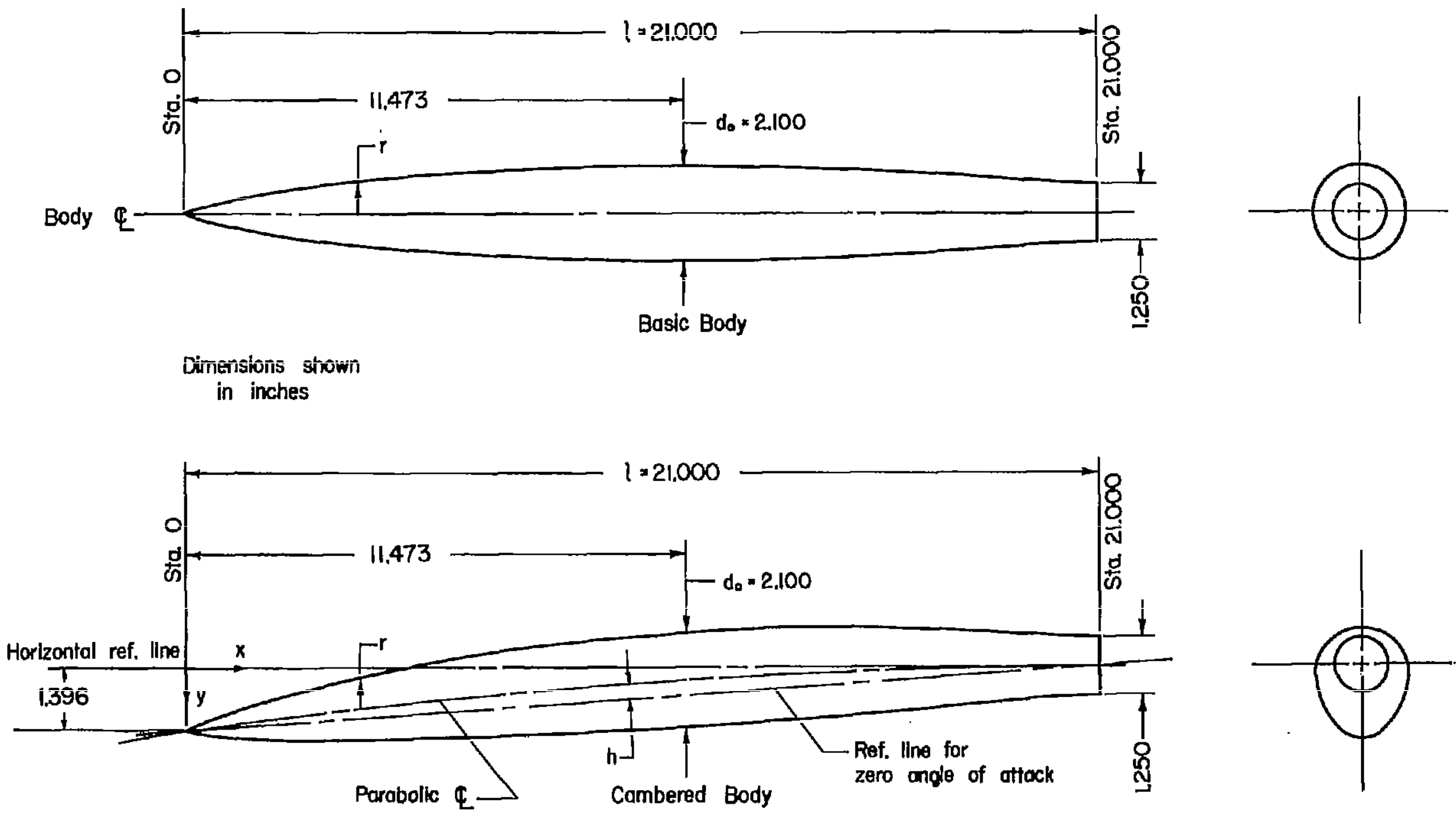

Figure 1.- Basic and cambered body models.

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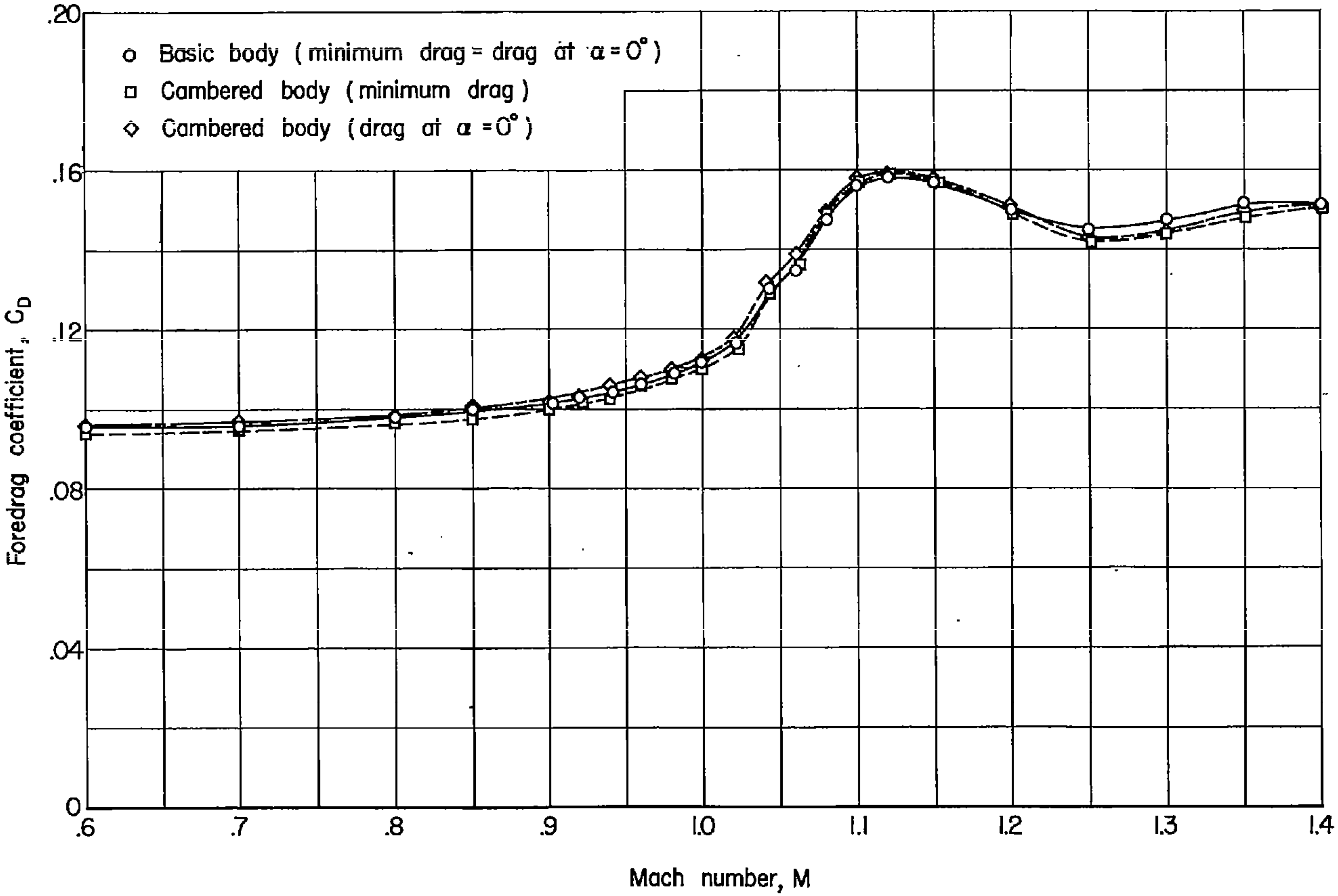

Figure 2.- Variation of foredrag with Mach number for bodies with and without camber.

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